

## STUDIES IN SURFACE FINISHING OF INCONEL718 FLAT SURFACE WITH MAGNETIC ABRASIVE FINISHING

AMIT CHOUDHARY<sup>1</sup> & HARISH KUMAR<sup>2</sup>

<sup>1</sup>Research Scholar, Department of Mechanical Engineering, Chandigarh University, Gharuan, Mohali, Punjab, India

<sup>2</sup>Associate Professor, Department of Mechanical Engineering, Chandigarh University, Gharuan, Mohali, Punjab, India

### ABSTRACT

*With technological developments in manufacturing industry, very hard and tough materials are being developed. Inconel 718 is one such material, which is a nickel based super alloy having high temperature and high-pressure applications. Inconel 718 is very difficult for machining, because of its materialistic properties. Surface finish produced after any machining process on inconel718, is generally not up to the required level. So, surface finishing of Inconel718 is a challenging job to tackle with. In the present research work, an attempt has been made for external surface finishing, of Inconel 718 flat surface (5mm thickness plate), by using magnetic abrasive finishing process. Several experiments have been designed and performed, to study the effect of three selected process parameters such as processing time, pole rotational speed and weight percentage of abrasive particles, on percentage improvement in surface finishing. An experimental set up has been developed, to investigate the performance in term of percentage improvement in surface finish and qualitative micro structural changes on the surface, by using SEM. For the analysis of experimental results, an ANOVA has been used. Experimental results indicate that, all the above-mentioned parameters have significant effect on surface finishing of Inconel718.*

**KEYWORDS:** Magnetic Abrasive Finishing, Inconel718, Surface Finish & Ferro-Magnetic Abrasive Particles

**Received:** Jun 24, 2017; **Accepted:** Jul 10, 2017; **Published:** Jul 14, 2017; **Paper Id:** IJMPERDAUG201715

### INTRODUCTION

Inconel 718 is a nickel based super alloy and extensively used in aerospace industry, power plant, marine industry, steam turbines, jet engines, pressure vessel etc., because of its high strength and high thermal resistance properties. As machining of Inconel 718 is a difficult task, still various researchers tried to improve and optimize machining process parameters, to get better surface finishing. Mall et al.[1], tried to optimize machining parameters of end milling in dry conditions, to achieve good surface finish of Inconel 718, using Taguchi method. Alauddin et al. [2], studied the effect of cutting speed and feed rate in end milling, by Tungsten carbide tool for surface finish, of Inconel 718. Zhong et al. [3] utilized cutting tools, made of coated and uncoated cermet and CBN, for machining of Inconel71 is that, they had studied surface finish, residual stress and hardness.

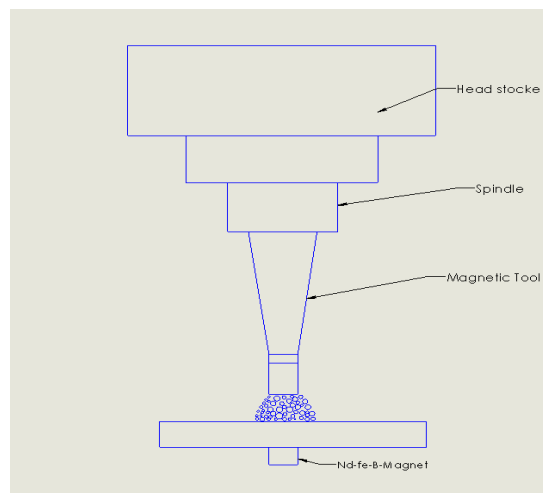
To finish hard surface of Inconel718, conventional finishing processes like lapping, honing, shot peening are not that much effective. Inconel 718 surface, can be finished by another recently developed process, called Magnetic Abrasive Finishing (MAF) Process. In MAF, work piece is kept between two poles of the magnet's north and South Pole. The gap between the work piece and the magnet is filled with the ferro-magnetic abrasive particles and the finishing is performed, in the presence of magnetic field. Ferro-magnetic abrasives are attracted towards the magnetic pole, which further leads for the formation of flexible magnetic brush. This magnetic

abrasive brush (MAB), further leads to the surface finishing. The smaller amount of material is removed from the surface while finishing.

Various researchers have successfully utilized magnetic abrasive finishing process, to finish different material surface. T. Shinmura et al. [4] studied magnetic abrasive process in which, generation of magnetic field due to finishing pressure, the finishing characteristics and principle process, is not explained. Mori et al. [5] performed experiments on SUS304 stainless steel and studied the effect of magnetic force on finishing process. Lin et al. [6] used magnetic abrasive finishing process to finish stainless steel SUS304's surface. Parameters varied were magnetic field, spindle revolution, feed rate, working gap, abrasive and lubricant. Imet al. [7] performed experiments on STS 304 cylindrical work piece, using a magnetic abrasive finishing process at 30,000 rpm. Surface roughness and change in micro diameter, were measured by using near line approach. Kwak et al. [8] experimented magnetic abrasive finishing process, to finish non-ferrous material, magnesium. Kala et al. [9] used magnetic abrasive finishing process, on double disk paramagnetic work piece, to measure the finishing force and torque, by varying upper and lower working gap, rotational speed, weight % abrasive particle and finishing torque. Sihag et al. [10] utilized MAF process, to finish tungsten work piece. Effect of various process parameters like weight % of abrasive particle, rotational speed of magnetic tool and working gap on surface roughness, was recorded. Results were calculated using Taguchi  $L_9$  orthogonal array. Wu et al. [11] performed experiments on stainless steel plate, by using a new method, ultra-precision magnetic abrasive finishing.

## EXPERIMENTAL SETUP

An experimental set up has been developed in which, a rotating magnetic tool was fixed, in the spindle of vertical milling machine (Figure 1), which is used for surface finishing, of Inconel 718 plate (250 x 250 x 5 mm). Magnetic tool is made up of aluminium rod ( $\varnothing 25 \times 125$ mm) and Nd-Fe-B permanent magnet, of size  $\varnothing 20 \times 22$ mm. Two hand wheel screws were available, to control the movement of bed on the right and left-hand side of the bed, and the other screw was available towards the upper side and lower side, which further moves the bed up and down, for maintaining the required gap between the magnetic tool and work piece (Figure 2). Vertical milling machine is capable to rotate the tool, from 80-520rpm. Two wooden blocks have been used, to keep the work piece at a certain height from the machine bed. Suitable fixtures have been used, to hold the work piece on machine bed. Another Nd-Fe-B magnet ( $\varnothing 20 \times 10$  mm) has been installed below the work piece, to enhance magnetic flux density (Figure 3).



**Figure 1: Schematic View of Experimental Setup**



**Figure 2: Photographic View of Experimental Set up**

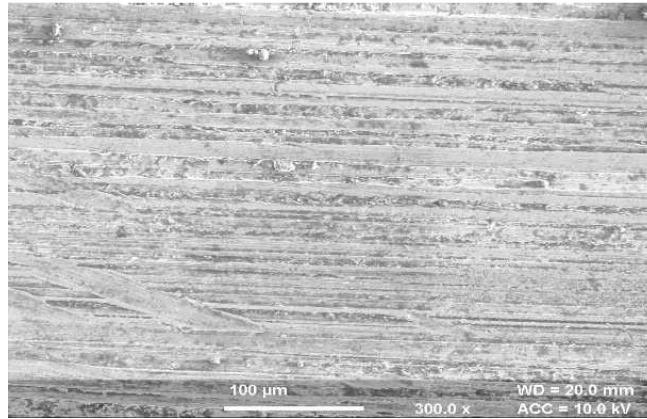


**Figure 3: Photographic View of Magnetic Tool with Supporting Permanent Magnet**

## **EXPERIMENTATION**

For the final experimentation, Inconel 718 work piece was fixed on a vertical milling machine bed, as shown in Figure 3. A magnetic tool was held in milling machine spindle and another supporting permanent magnet was placed below the work piece. A strong magnetic field is induced between two magnets. Due to machining operation on Inconel 718 work surface, it has very rough surface with the number of tool marks and asperities. Figure 4, shows SEM photograph

of the machine Inconel 718 surface, which indicates lot of cutting tool marks and burrs. These are produced due to high cutting forces, during machining of Inconel 718 surface.



**Figure 4: SEM Photograph of Inconel 718 Rough Surface**

For magnetic abrasive finishing of Inconel 718 surface, there are many process parameters like work material, processing time, pole rotational speed, pole-work gap, shape of pole, quantity of abrasive particles and composition of ferromagnetic abrasive particles etc, which can affect the finishing process. On the basis of thorough literature survey and experimentation setup capabilities, three major process parameters: processing time, pole rotational speed and weight percentage of abrasive particle and their ranges, has been selected for final experimentation (Table 1).

A mixture of abrasive particles, made up of silicon carbide ( $\phi$  40  $\mu$ m average particle size) and electrolytic iron particles ( $\phi$  300  $\mu$ m average particle size) is used as ferro-magnetic abrasive particles, for the surface finishing of the work surface. Soluble type barrel finishing compound (2 ml) has been used for each experiment. A gap of 3mm is kept between magnetic tool and Inconel 718 plate, and the gap is filled with ferro-magnetic abrasive particles (Quantity: 3 gms). Due to high magnetic flux density between two magnets, a magnetic abrasive brush is formed over the work surface, of Inconel 718 that acts as a finishing tool, while rotating over the surface and removing surface irregularities.

**Table1: Experimental Conditions**

Work piece	Inconel 718 (250×250×5mm)
Magnetic Tool	Nd-Fe-b Permanent Magnet ( $\phi$ 20×22mm)
Supporting Magnet	Nd-Fe-b Permanent Magnet ( $\phi$ 20×10 mm)
Process parameters and their Range	Pole Rotational Speed :140-400rpm Processing Time:30-90 minutes Weight %age of Abrasive: 20-40 %
Ferro-magnetic abrasive particles	Quantity: 3 gms Ferrous particles: Electrolytic iron particles ( $\phi$ 300 $\mu$ m) Abrasives particles: Silicon Carbide ( $\phi$ 40 $\mu$ m)

**Table2: Coded and Real Level of Independent Variables**

Parameters	Symbol	Level		
		-1	0	1
Processing Time (mins)	A	30	60	90
Pole Rotational Speed (rpm)	B	140	270	400
Weight %age of Abrasive (%)	C	20	30	40
<b>Constant Parameters</b>				
Work piece material	Inconel 718			

Geometry of Magnetic Tool	Ø20×22mm
Dimensions of Work piece	250 x 250 x 5 mm
Working gap between magnetic tool and work piece	3 mm
Response Characteristics: Percentage Improvement in Surface Finish(PISF)	

Flat surface of Inconel 718, having dimensions 250×250×5mm, has been selected for the final experimentation on vertical milling machine. Magnetic tool was held in vertical milling machine spindle, and work piece was held on the machine bed, with suitable fixtures. Another supporting permanent magnet was placed below the workpiece. Gap between magnetic tool and work piece, was filled with ferro-magnetic abrasive particles.

In the present research work, response surface methodology has been used, to design the experiment. Three independent variables i.e., Processing Time, Pole Rotational speed and Weight % of abrasives, which can influence the surface finish were selected and could be varied up to three levels (Table 2).

**Table 3: Experimentation Plan**

Exp. No.	Std	Processing Time (mins)	Pole Rotational Speed (rpm)	Weight % Age of Abrasive
1	4	1	1	0
2	5	-1	0	-1
3	8	1	0	1
4	6	1	0	-1
5	14	0	0	0
6	12	0	1	1
7	16	0	0	0
8	2	1	-1	0
9	7	-1	0	1
10	11	0	-1	1
11	1	-1	-1	0
12	13	0	0	0
13	9	0	-1	-1
14	3	-1	1	0
15	15	0	0	0
16	17	0	0	0
17	10	0	1	-1

17 experiments were conducted as per experimental plan (Table 3). The experiments were performed randomly to avoid any bias in the final results. After experimentation, roughness of surface work-piece was measured with the help of roughness tester. Surface finish was measured at least three points to obtain final results for the surface finish. Final value of the surface finish was based on the average value of above three points and percentage of improvement in surface finishing (PISF) for all the seventeen experiments were calculated by comparing their average surface roughness values of unprocessed surface with processed surface. Initial values for surface roughness varies from 0.317 µm to 1.031 µm and final values for surface roughness varies from 0.046 µm to 0.254 µm. Final results of Percentage improvement in surface finishing was shown in table 4. An ANOVA has been used to analyse the results.

**Table 4: Experimental Responses**

Exp. No.	Order of exp.	Independent Parameters (Coded)			PISF
		A	B	C	
1	4	1	1	0	64
2	5	-1	0	-1	89

3	8	1	0	1	93
4	6	1	0	-1	88
5	14	0	0	0	89
6	12	0	1	1	67
7	16	0	0	0	87
8	2	1	-1	0	77
9	7	-1	0	1	75
10	11	0	-1	1	85
11	1	-1	-1	0	66
12	13	0	0	0	94
13	9	0	-1	-1	84
14	3	-1	1	0	65
15	15	0	0	0	81
16	17	0	0	0	84
17	10	0	1	-1	52
A- Processing Time B- Pole Rotational Speed C- Weight % of Abrasive					

## RESULTS AND DISCUSSIONS

After final experimentation on 17 work pieces of Inconel718, each and every work surface was tested for surface finish. PISF has been calculated and then analysed using design experiment software. Effect of three different process parameters have been analysed and discussed as follows: -

### Simultaneous Effect of Processing Time and Pole Rotational Speed on PISF

Figure 5 shows the simultaneous effect of processing time and pole rotational speed on percentage improvement in surface finish.

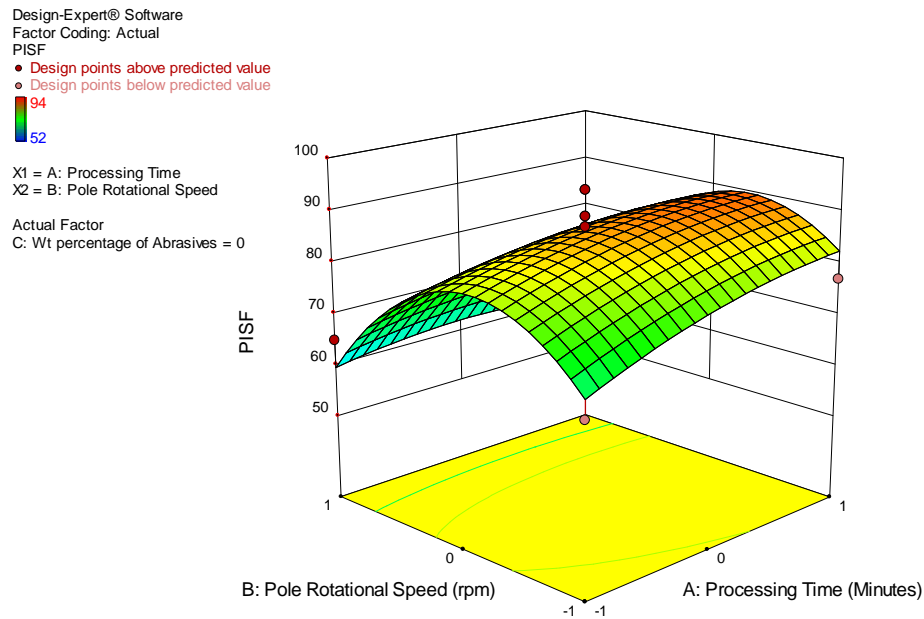
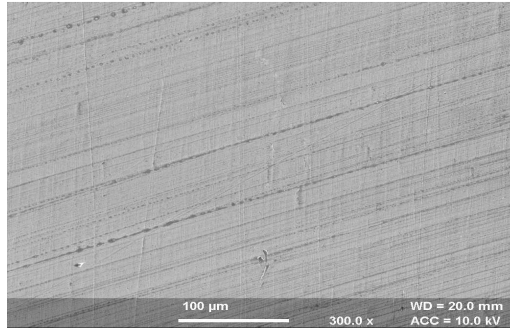
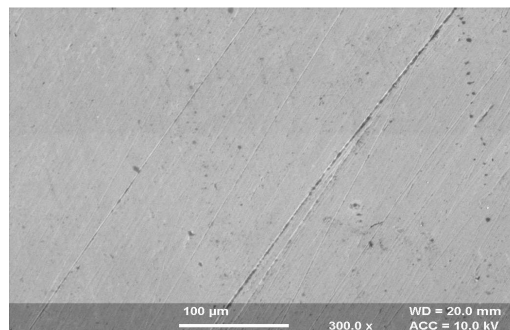


Figure 5: Effect of Simultaneous Variation in Processing Time and Pole Rotational Speed on PISF

In figure 5, it is clear that at minimum processing time, -1(30 minutes) and minimum pole rotational speed, -1(140 rpm) there is considerable increase in PISF. As the values of both process parameters are increased, PISF keeps on increasing simultaneously. But PISF is maximum at maximum value of processing time, 1(90 minutes) and pole rotational speed which lies between minimum speed, -1(140 rpm) and average speed, 0(270 rpm). PISF starts decreasing with increase in pole rotational speed. PISF is lowest at highest pole rotational speed and at lowest processing time.



**Figure 6 (a): SEM Photograph at Processing Condition Processing Time: 30 Minutes, Pole Rotation Weight % of Abrasive Particles: 30**

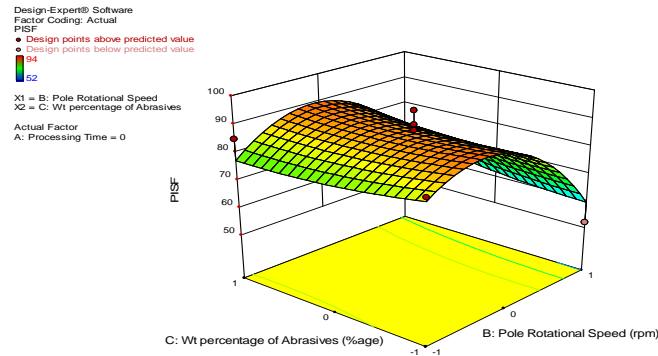


**Figure 6(b): SEM Photograph at Processing Condition: Speed: 400rpm Processing time: 90 Minutes, Pole Rotationspeed: 140 rpm, weight % of Abrasive Particles:30**

Effect of variation in processing time and pole rotational speed can also be observed in SEM photographs in figure 6(a) and 6(b). It is evident that as compared to initial surface (Figure 4) work surface is improved at minimum processing time, 30 minutes and maximum pole rotational speed, 400 rpm (Figure 6a). But surface is very well improved at maximum processing time, 90 minutes and minimum pole rotational speed, 140 rpm. It may be due to the fact that at higher pole rotational speed, ferro-magnetic tools produce scratches rather than finishing.

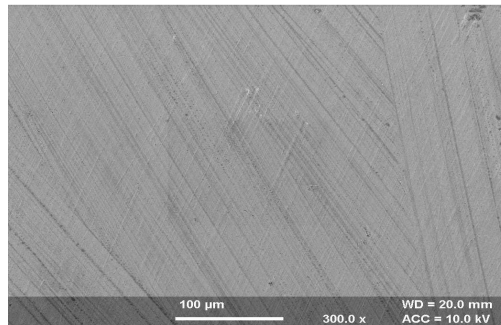


### Effect of Pole Rotational Speed and Weight %Age of Abrasive Particles

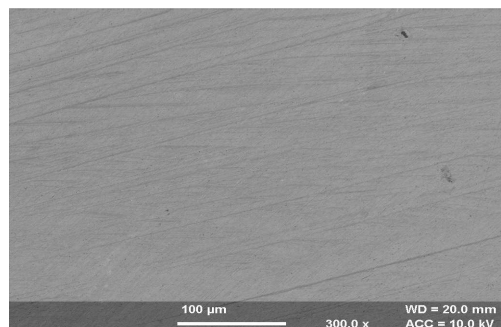


**Figure 7: Effect of Simultaneous Variation in Pole Rotational Speed and Weight %age of Abrasive Particles on PISF**

Effect of simultaneous variation in pole rotational speed and weight %age of abrasive particles is shown in figure 7. It is clear that PISF is minimum at maximum pole rotational speed (400 rpm) and minimum weight %age of abrasive particles (20 %). It may be due to the reason that at higher pole rotational speed, there will be more surface abrasion rather than finishing. PISF is maximum at average pole rotational speed (270 rpm) and maximum weight %age of abrasives (60%). With average pole rotational speed and maximum weight %age of abrasives particles, most of the surface asperities are removed.



**Figure 8 (a): SEM Photograph at Processing Condition Processing Time: 60 Minutes, Pole Rotation Weight % of Abrasive Particles: 20**



**Figure 8(b): SEM Photograph at Processing Condition Speed: 400rpm Processing Time: 60 Minutes, Pole Rotationspeed: 140 rpm, Weight % of Abrasive Particles: 60**

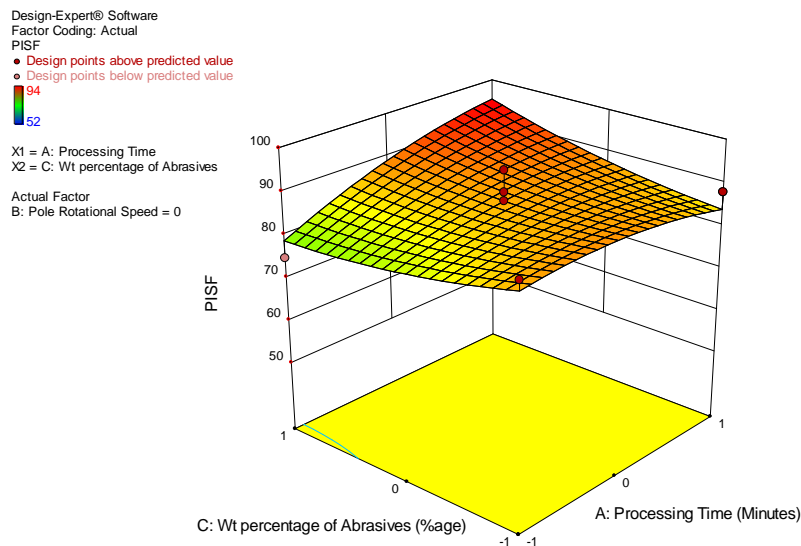
Figure 8(a) and 8(b) shows SEM photographs of work surfaces processed under different processing conditions by



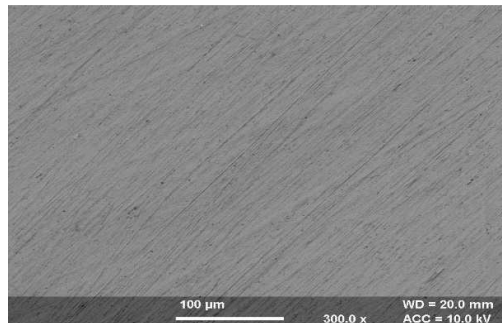
varying pole rotational speed and weight %age of abrasive particles. From SEM photographs, it can be easily observed that condition of work surface is far better lower pole rotational speed and higher weight %age of abrasives.

### Effect of Processing Time and Weight %Age of Abrasive Particles

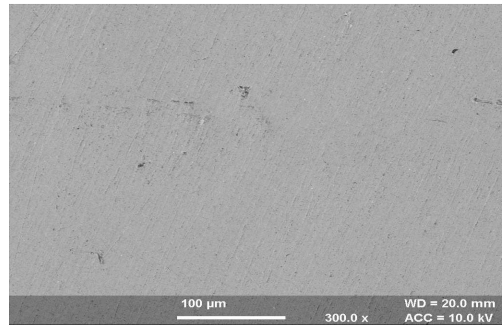
Figure 9 shows effect of simultaneous variation in processing time and pole rotational speed on PISF. It can be observed that PISF is minimum at minimum processing time (30 minutes) and minimum weight %age of abrasive particles. With simultaneous increase in both process parameters there is corresponding increase in PISF and reaches its maximum value at maximum values of processing time (90 minutes) and weight %age of abrasive particles(40%). SEM photographs (Figure 10.a and 10.b) also provethis observation. It can be hypothesised that processing the work surface with ferro-magnetic particles containing 40% of abrasive particles, a strong flexible magnetic abrasive brush is formed. This brush easily removes most of surface irregularities by abrading maximum peaks on work surface when processing for 90 minutes. All tool marks have been removed and finished surface with very small surface roughness can be achieved.



**Figure 9: Effect of Simultaneous Variation in Processing Time and Pole Rotational Speed on PISF**



**Figure 10 (a): SEM Photograph at Processing Condition Processing Time: 30 Minutes, Pole Rotation Weight % of Abrasive Particles: 20**



**Figure 10(b): SEM Photograph at Processing Condition speed: 270rpm Processing Time: 90 Minutes, Pole Rotation Speed: 270 rpm, Weight % of Abrasive Particles:40**

## CONCLUSIONS

After analysing experimental results, following conclusions can be drawn: -

- It is possible to finish Inconel 718 work surface with magnetic abrasive finishing process.
- There is a considerable effect of three selected process parameters i.e., processing time, pole rotational speed and weight % of abrasive particles, on percentage improvement in surface finish.
- Processing time is a major process parameter, which influences the finishing process. Higher values of processing time gives better surface finish.
- Medium values of pole rotational speed (270 rpm), is the most favourable speed for higher percentage improvement, in surface finish.
- Effect of weight % of abrasive particles, depends upon the other two process parameters. But still better surface finish can be achieved, with higher weight % of abrasive particles (40%).

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